

Asymmetric MRI Systems: Shim and RF Coil Designs

S. Crozier, H. Zhao, L.K. Forbes⁺, B. Lawrence, D. Yau, K. Luescher, W. Roffmann and D.Doddrell

Centre for Magnetic Resonance, The University of Queensland, Qld 4072 and ⁺School of Mathematics and Physics, The University of Tasmania, GPO Box 252-37, Hobart.

We have recently introduced the concept of asymmetric clinical MRI systems (1,2). The potential advantages of these systems include a reduced perception of claustrophobia by patients and better physician access to the patient. For asymmetric magnet systems to be useful as a clinical system, asymmetric shims and RF coils must be implemented, and in this work we describe new design methodologies for both.

Introduction

We have recently (1,2) shown that Current Density Mapping techniques are useful for the design of asymmetric MRI magnets, ones in which the dsv is moved towards one end of the magnet system (see Fig. 1). For a complete asymmetric system compatible shims, gradient and RF coils are, of course, required.

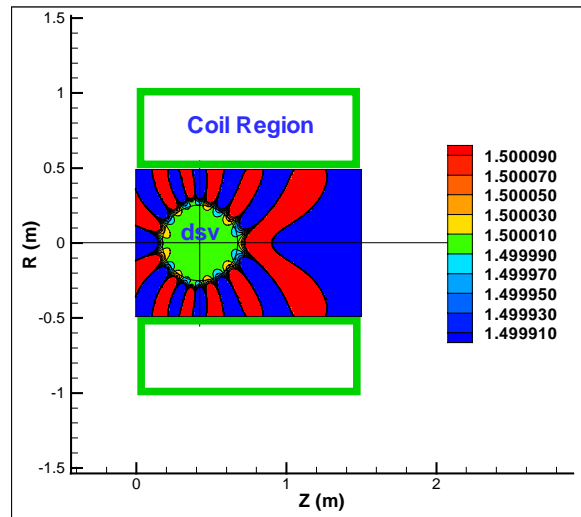


Fig. 1 – An example of an asymmetric MRI magnet.

Shims and Gradients

The shims and gradient coil designs required a genuine finite length algorithm in which the target region may be placed asymmetrically with the coil structure. To achieve this we have devised a new design methodology, based on the general target-field approach (3), but using a more generalised integral-equation methodology.

In essence we need to solve the first-kind Fredholm equation

$$H_T^c(z) = - \int_{-L}^L j_\theta(z') M(z, z'; a, c) dz' \quad pL < z < pL$$

in which $j_\theta(z)$ is the desired current density to generate the target field $H_T(z)$, while $-1 < p < 1$ and L is the coil half length. This equation is very ill-conditioned and straightforward solution methods yield spurious oscillations in $j_\theta(z)$. We have successfully solved this equation using a method equivalent to Tikhonov regularization (4). Fig 2 shows the current density for a z-gradient in which the total coil length was 0.4m, the diameter 0.2m and asymmetry parameters $p=-0.7$, $q=0.1$. Coil patterns have been generated for all (asymmetric) zonal shims using this method and the resulting spherical harmonic expansions within the dsf differ from targets by less than 1%.

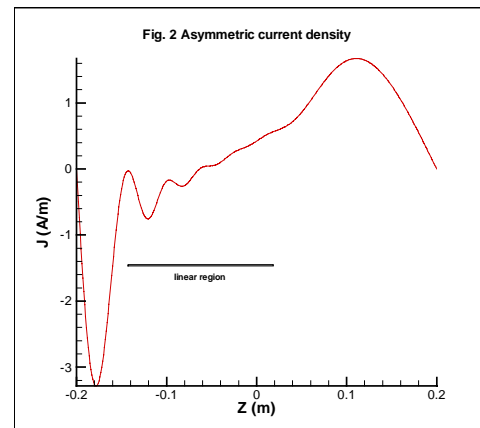


Fig 2 – An asymmetric current density for a z-coil.

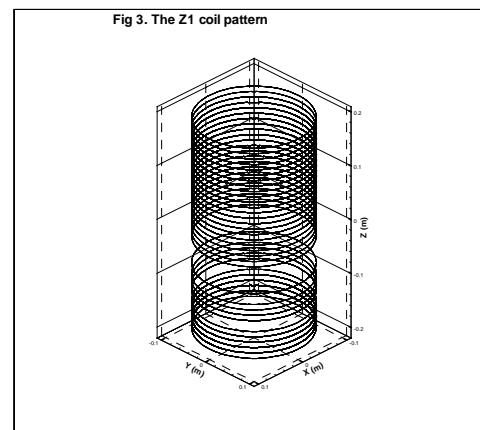
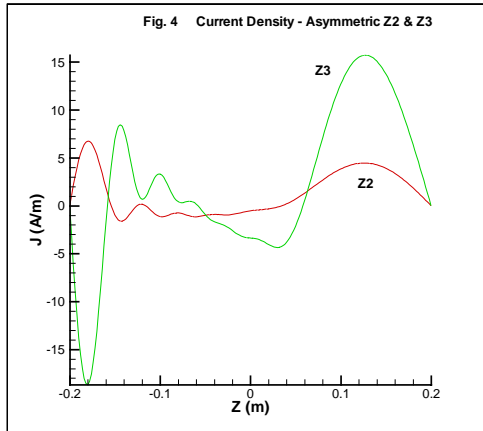


Fig 3. The Z1 coil pattern

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Figure 2 shows the wire pattern of an asymmetric Z shim corresponding to the current density of Fig. 2. Figure 4 shows the current densities for the more difficult asymmetric Z2 and Z3 designs.



RF Coils

In designing the RF coils, we had the goal of making a cylindrical system, open at both ends, in which the useful RF region was asymmetric. In this work we have used roof-top basis functions (see Fig. 5) for the determination of asymmetric current densities. These basis functions are commonly used for stripline antenna design.

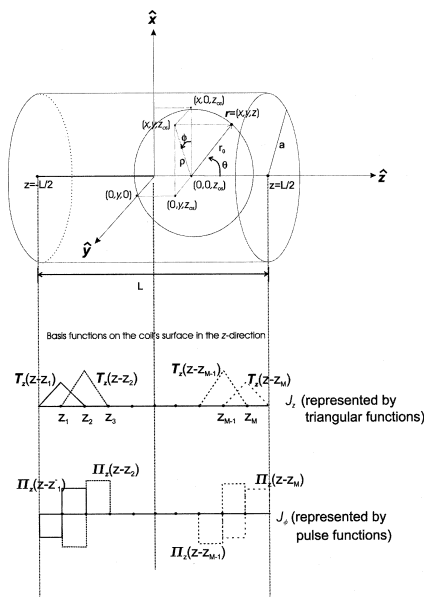


Fig. 5 The basis functions for the asymmetric RF coil design.

Figure 6 shows the resultant current density from the design process using the roof-top basis functions.

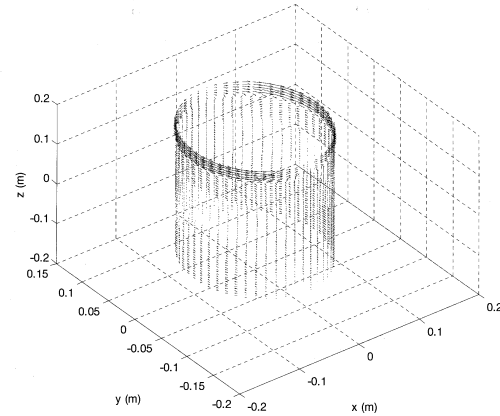


Fig. 6 An asymmetric current density.

A method-of-moments analysis is then used to map the current density into a coil pattern. Figures 7 and 8 show the patterns and generated RF fields for a 190 MHz asymmetric coil.

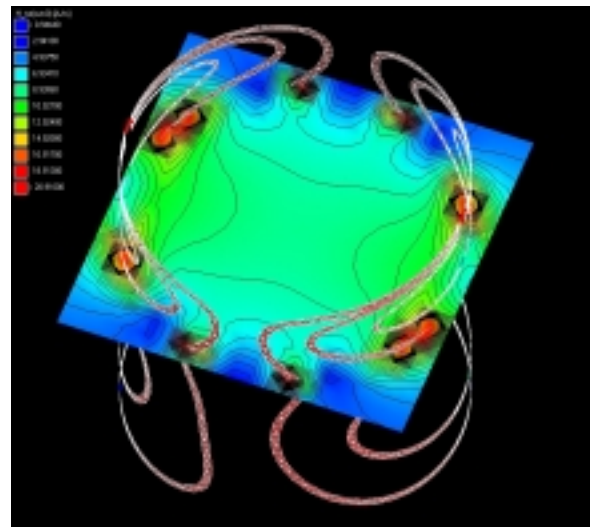


Fig. 7. The coil structure and generated RF magnetic field at 5% contour level.

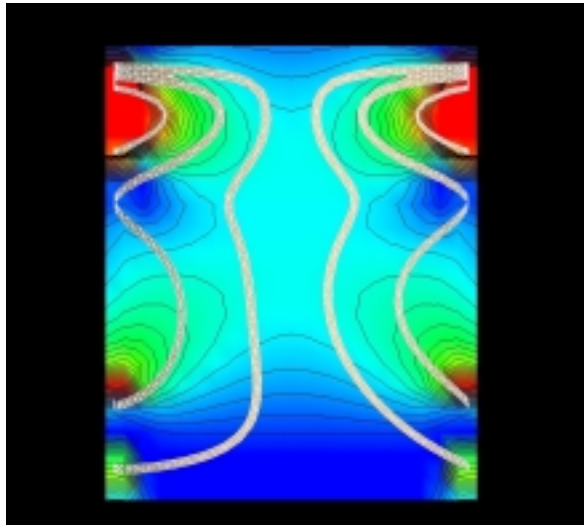


Fig. 8 A sagittal view of the coil structure of Fig. 7.

These results indicate that a suitable RF field pattern, very close to the targetted region has been achieved.

Conclusion. The success of these design methods brings the full implementation of a clinical, asymmetric MRI system one step closer to reality.

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